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Development of one-coordinate gaseous detector for wide angle diffraction studies.

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ABSTRACT: A one-coordinate gaseous detector of soft X-ray photons for wide-angle X-ray scattering (WAXS) studies is being developed. The detector operates in counting mode and is based on multi-stage Gas Electron Multiplier(GEM). Full size detector is assembled and has 67 degrees aperture with 350mm distance to the source, readout multi-strip structure with 2048 strips at 0.2mm pitch and is partially equipped with readout electronics in the central part. Main parameters of the detector have been measured with 8keV X-ray beam at VEPP-3 synchrotron ring. Spatial resolution of 470 μm (FWHM) has been demonstrated that will allow to distinguish diffraction spots at 0.1 degrees.

KEYWORDS: WAXS, GEM, X-ray detector.

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Contents

1. Introduction.

Any detector for the studies of X-ray diffraction to large angles has to present essentially curved geometry with conversion, readout and possibly amplifying structure that surrounds the scattering source. The detector OD3 with angular aperture up to 30° for powder diffraction experiments has been already designed and constructed in Budker Institute of Nuclear Physics [1]. This detector has been built on the basis of wire chamber. However further development of a detector with larger angular aperture and considerably curved cylindrical geometry is impossible on such basis. Thus in order to cover the wider range of diffraction angles the Gas Electron Multiplier (GEM) [2] was proposed to be used as the multiplying element.

GEM is a thin plastic foil double clad with copper layers from both sides and pierced with regular array of small diameter holes. Regular GEM is produced of 50μm thick kapton foil and has 140μm holes pitch and 80μm holes diameter. Gas amplification occurs in the GEM holes when high voltage is applied between the two foil sides. GEMs can be cascaded and in a triple-GEM cascade can provide stable gain up to and higher than $\sim 10^5$ in a regular gas mixures like $Ar - CO_2$(70-30) [3].

Flat and flexible amplifying structure of GEM allows to prepare arc-shaped GEM cascade that can surround the scattering source in a WAXS experiment. Such approach can solve the problem of large angular aperture for a gaseous detector.

The first measurements with the small prototype and simulations demonstrating feasibility of this approach were described elsewhere ([4], [5]). This paper presents the first results obtained with full-size detector.

2. Detector design and experimental set-up.

The detector for WAXS studies based on cascaded GEM (OD4) is shown schematically in Fig. 1. X-rays from the scattering source get into the gas box through the Be window and are absorbed in 5.5mm thick drift gap between the drift cathode and the top GEM. The triple-GEM stack with GEM to GEM distance of 1.5mm is attached on top of the multi-strip PCB at a distance of 2.5mm.
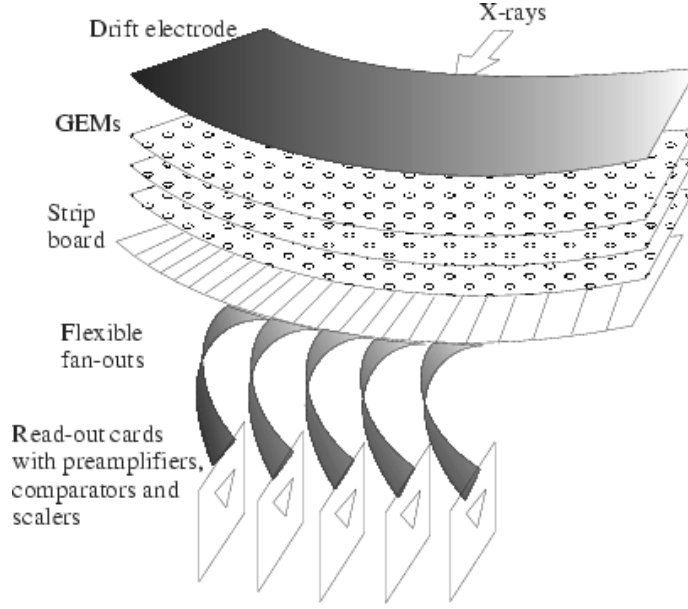
Figure 1. Schematic view of OD4 design.

Drift cathode, GEMs and PCB have arc shape with the center at the scattering source. Strips of the PCB are positioned along radii of the circle with the center at the source. The PCB contains 2048 strips with the pitch of 0.2mm at the entrance side.

The detector is intended to work with soft X-rays in the range of 5keV to 15kev and is filled with $Ar - CO_2$(3:1) mixture at atmospheric pressure.

The OD4 electronics is implemented on the basis of preamplifier-shaper chip IC31A [6] developed for the electronics of PHENIX detector at RHIC (BNL, USA). Each strip of the PCB is connected to an input of the preamplifier-shaper through the flexible cable. The outputs of preamplifiers are connected to the comparators with single and adjustable threshold and logical pulses after the comparators are counted by scalers.

At present the final electronics is not yet ready and only 32 strips in the center of the detector have been equipped with preamplifier-shapers and comparators. 64 strips from both sides of the equipped area have been connected to ground to ensure uniform field in the central region. The detector during assembling is shown in Fig. 2 where triple-GEM cascade installed on top of the PCB can be observed. Fig. 3 demonstrates assembled detector.

The GEM electrodes and drift cathode have been powered through the single-line resistive divider that was adjusted to minimize transverse diffusion and have reasonable GEM transparency during electrons drift from drift gap to the PCB. The adjustment of the voltages across transfer gaps, induction gap and drift gap has been performed for the conditions when the voltages across GEMs provide total effective gain of the whole cascade around 10000.

For the measurements described in this paper the OD4 has been installed at one of synchrotron radiation lines at VEPP-3 electron ring. After monochromator the X-ray beam with 8.3 keV energy was collimated by 20μm slit. Effective beam size at the entrance window of the detector was 20μm in horizontal and $\sim$1mm in vertical. The detector was positioned with 3 stands that allow precise
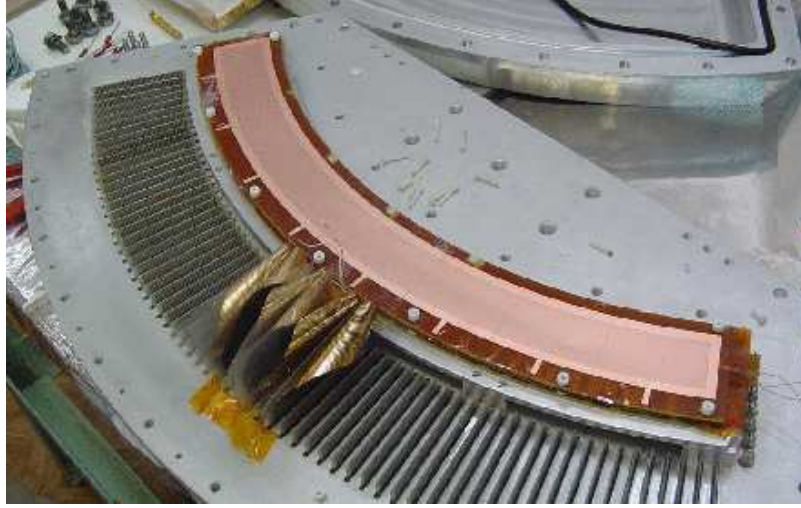
Figure 2. Photo of the detector during assembly. Flexible kapton cables are connecting 160 strips to the feed-throughs in the central part of the detector. Triple-GEM cascade is installed on top of the PCB.

Figure 3. View of the assembled detector.

rotation around vertical axis, movement in horizontal and vertical directions. With these stands the strips equipped with the electronics could be aligned along the beam as the source was not at the focus of the detector(350mm).

3. Results and discussion

When an X-ray photon is absorbed in the drift gap of the detector, after charge transport and am-

plification the final charge cluster occupies in average more than 1 strip. The charge distribution and its effect on spatial resolution was discussed in details in our previous paper([4]) where the results of simulations were compared to the measurements with the prototype of the present detector. However the important outcome of the charge distribution over several strips is that even if the detector is irradiated with the constant flux of photons, the counting rate will depend on the comparators threshold, gas gain and the flux distribution in space. Fig. 4 demonstrates the counting rate as a function of voltage at the resistive divider in 1 arbitrary channel, coincidence between 2,3 and 4 neighboring channels while the detector has been uniformly irradiated with Fe^{55} 5.9keV photons. The comparators threshold has been close to 150mV in this measurement that, according to the electronic calibration (measured amplifier gain was 14mV/fC), corresponded to the gas gain of $\sim$300 for 5.9keV X-rays. Counting rate of a single channel is increasing in the whole range of voltages as more channels get hit with increasing gas gain. Above Vd=2750V most of the rate is produced by coincident hits of several channels.

However the counting rate dependence on voltage looks differently if the detector is irradiated with narrow X-ray beam. If all the photons are absorbed within one channel and no charge can come from the neighboring areas, the counting rate becomes constant when all the signals induced by absorbed photons become larger than the threshold. In Fig. 5 the counting rate vs voltage dependence for several comparator thresholds are presented. The 20μm beam of 8.3 keV photons hits the center of the channel in this measurement. The starting points of counting rate plateau give information about average signal value at a given voltage, thus the gain-voltage characteristic can be derived from this data. Table 1 summarizes data on counting rate plateau starting voltages (50% level of plateau), corresponding threshold values and gain values, calculated using electronic calibration.

Plateau starting voltage, V	Threshold, V	Gain
2420	0.3	450
2480	0.53	795
2500	0.77	1155
2520	1.0	1500

Table 1. Counting rate plateau starting voltage (50% level), corresponding comparator threshold and gain value, calculated from electronic calibration.

This data is plotted in Fig. 6 with exponential fit through the experimental points. The gain-voltage dependence fits well to similar data from [3] and [4].

For the studies of spatial resolution the detector has been moved horizontally in such a way that 20μm wide X-ray beam has scanned the area of several detector channels. Counting rate as a function of beam position for each channel (channel response curve) has been used for characterization of the spatial resolution. The measurements have been performed at a different detector voltages and different comparator thresholds in order to observe the dependence of resolution on these parameters. An example of the set of channel response curves for Vd=2580V ($V_{GEM} \sim$360V, Gain$\sim$3000) and the threshold that provides 90% efficiency in the central channel is shown in Fig. 7.
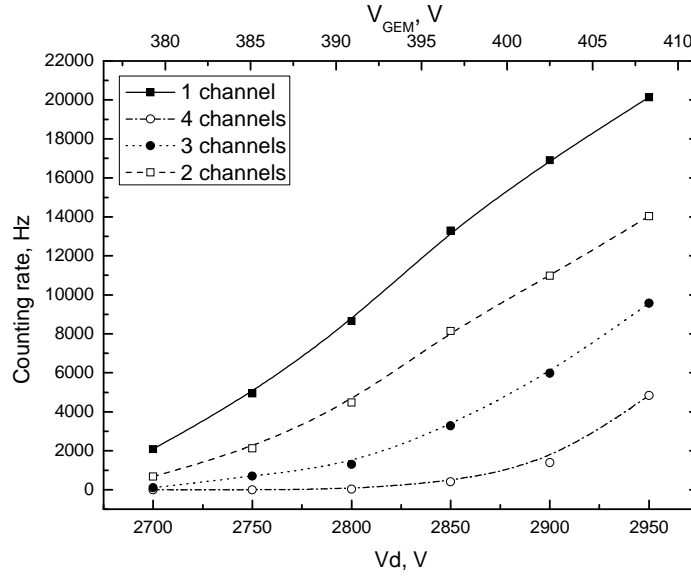
Figure 4. Counting rate as a function of voltage at the resistive divider while the detector is uniformly irradiated by 5.9keV photons. The voltage across each GEM is shown at the top scale. The rate of single counts, double-, triple- and quadruple- coincidences is shown.
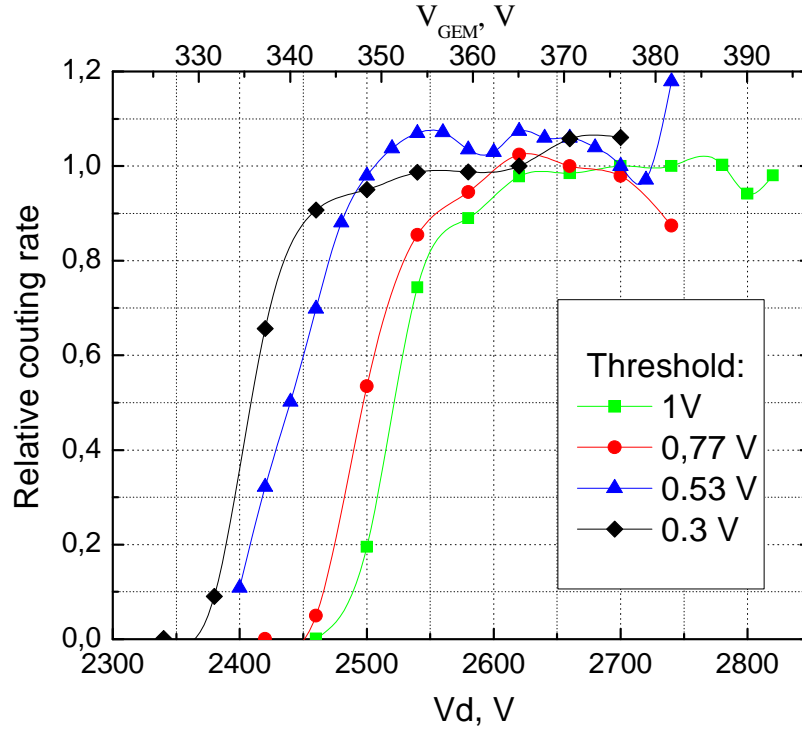

Figure 5. Counting rate as a function of voltage at the resistive divider while the detector is irradiated by thin beam of 8.3keV photons. The voltage across each GEM is shown at the top scale. Several dependences corresponding to different comparator thresholds are shown.

Different counting rate of the left and central channels can be explained by different gain in
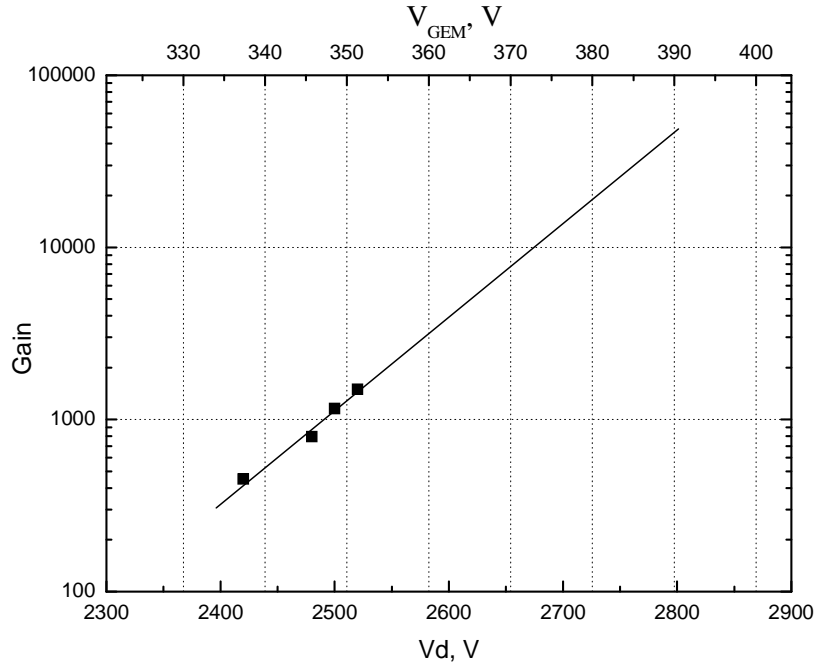
Figure 6. Gain as a function of voltage at the divider (bottom scale) and single GEM(top scale). Exponential fit is plotted through the experimental points.
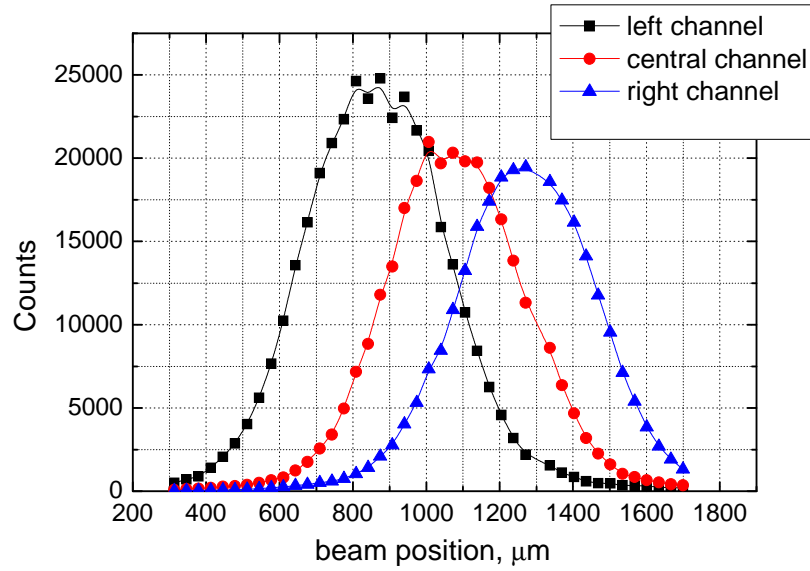

Figure 7. Channel response curves for 3 channels scanned with 20μm wide X-ray beam. Voltage at the divider Vd=2580V, the comparator threshold provides 90% efficiency in the central channel.

these areas. The left channel has slightly higher gain and thus reach full efficiency already at this voltage and threshold. The lower is the threshold the smaller signal can be detected and thus the channel response curve is becoming wider. On the other hand when the threshold is too high

the efficiency starts to drop. Fig. 8 demonstrates the dependence of spatial resolution (FWHM of channel response curve) on the efficiency, derived from several measurements of channel response curves. All these measurements have been done at Vd=2580V.

Thus spatial resolution can be tuned in a wide range by the adjustment of the comparator threshold and/or the detector gain. At the level of 90% efficiency the resolution is close to 470μm and can be improved to FWHM$\sim$330μm at the expense of the efficiency that drops down to 50% in the latter case.

Spatial resolution obtained with 90% efficiency is good enough to allow separation of two diffraction spots at angular distance of 0.1 degree that corresponds to $\sim$0.6mm for this detector. The image of two such spots positioned symmetrically with respect to the central channel is calculated using the channel response curve from Fig. 7 and shown in Fig. 9.

High rate capability is one of the advantages of GEM based detectors over wire chambers. Smaller amplifier cells (140μm distance between holes in GEM) allow faster charge removal and thus produce lower space charge that affects the gain. Rate capability of cascaded GEMs was demonstrated up to the level of 10^5 Hz/mm^2 of 8 keV photons ([7]). In OD4 we have been aiming to get the counting rate capability of up to 100kHz per 0.2mm wide channel.

The measurement of rate capability of OD4 was performed with 20μm wide beam of 8.3keV photons aligned at the center of a channel. The beam was attenuated with 50μm thick aluminum foils. In each subsequent measurement 1 foil was removed to increase the rate. Every time when the measurement with reduced number of foils was completed the additional normalizing measurement was performed with 12 foils. The normalizing measurement was necessary to correct the results for beam intensity variations that happened due to monochromator movements and electron beam instabilities. All the measurements have been done at Vd=2580V (gain$\sim$3000) and the comparator threshold adjusted to provide 90% efficiency of plateau level.

After the completion of all the measurements and correction on the normalizing data, the effective absorption of the foil has been calculated for each subsequent pair of measurements. This value has included the absorption by itself and possible additional rate reduction due to limited rate capability. Then the average effective foil absorption and its variance have been calculated using only the set of measurements where foil absorptions have been constant (at lower rates). The linear rate scale has been calculated using the rate value in the first measurement at the lowest rate and average foil absorption. The relative efficiency has been obtained as the ratio of the measured rate and the calculated linear rate. The variance of foil absorption value has been used to calculate the variance of the linear rate and the corresponding variance of the relative efficiency.

The result of this study is shown in Fig. 10. Within the measurement errors that have been mainly determined with the beam instabilities, the detector efficiency does not depend on the photons rate up to $\sim$100kHz/channel. Indeed we could expect this result because the effective area where charge is produced by the X-ray beam is spread over 0.2mm*30mm=6mm^2 (0.2mm is channel width, 30mm is strip length) and maximum charge rate is equivalent to only $\sim$20kHz/mm^2 of 8.3keV photons at gain$\sim$3000.

4. Conclusion.

Full size detector for WAXS studies has been assembled and tested at the synchrotron radiation

line at VEPP-3. The detector has been partially equipped with electronics that included amplifier-shaper, comparator and scaler in each channel. OD4 has demonstrated stable performance with 8.3 keV photons in the range of gains from ∼500 to more than 10000.

Spatial resolution of the detector can be tuned with the comparator threshold and gas gain and it appeared to be simple function of efficiency when the latter is lower than 100%. For 90% efficiency the spatial resolution is ∼470μm (FWHM of the channel response curve). Such resolution is enough to separate clearly the diffraction spots at an angular distance of 0.1 degree, that was initially established as a main requirement for OD4. The measurements of spatial resolution and efficiency in a wide range of gas gains and comparator thresholds have shown that the detector can work at rather low gains (below 1000) and by threshold adjustment the resolution and efficiency can be chosen at optimal level. We hope that for the operation at such gains the number of GEMs in the cascade can be reduced to 2 or even to 1 and this will be checked in future studies.

Rate capability of OD4 was tested up to the rate of ∼150kHz/channel. No significant degradation of efficiency has been detected.

The electronics that have been used for the measurements was not final. The boards that contain the amplifier-shapers and comparators will be connected to the motherboard that will collect data from all the 32-channel amplifier boards, control them and communicate with the computer. The first version of the final electronics including the motherboard and amplifier cards for total number of 256 channels will be ready during 2008.

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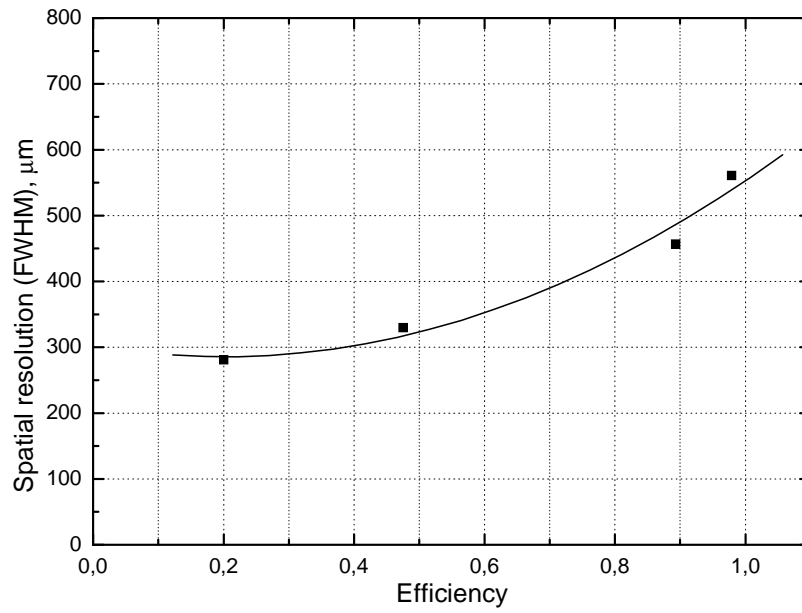[7] A.Bressan, et.al., Nucl. Instr. and Meth., A 425 (1999) 262

Figure 8. Spatial resolution (FWHM of channel response curve) as a function of efficiency. Voltage at the divider Vd=2580V.
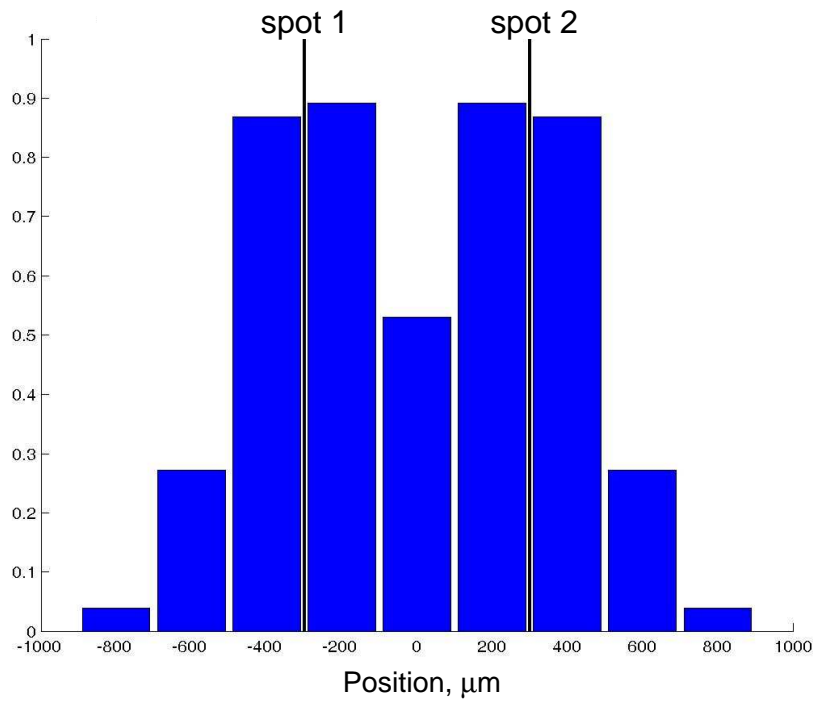

Figure 9. Image of two diffraction spots separated by 0.1 degrees (0.6mm at 350mm distance to the scattering source). Image is calculated using channel response curve with 470μm FWHM.
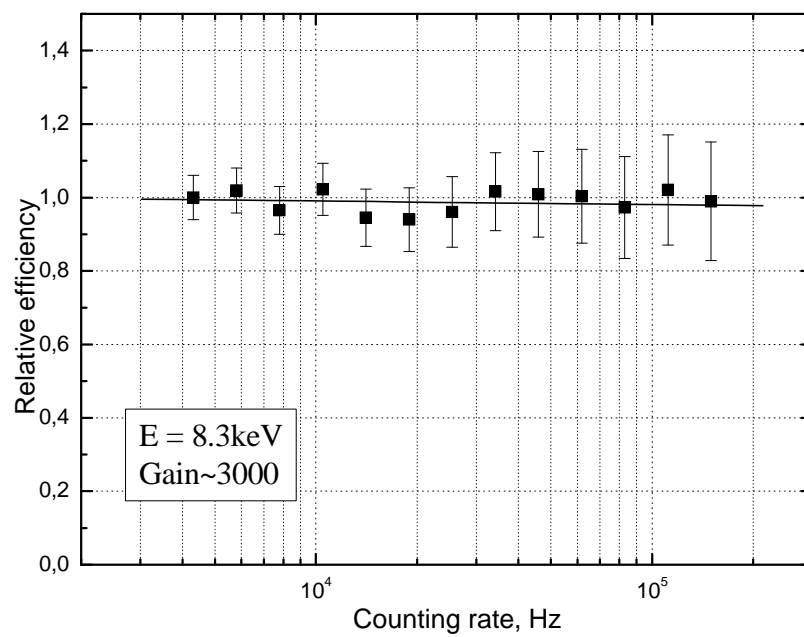
Figure 10. Rate capability of OD4. The measurement has been performed with 20μm wide X-ray beam aligned at the center of a channel.